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USE OF THE MOISTURE EQUIVALENT FOR THE INDIRECT DETERMINATION OF THE HYGROSCOPIC COEFFICIENT

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INTRODUCTION

The maximum amount of soil water available for growth and for the maintenance of life in the case of ordinary crop plants appears to be approximately equal to the free water—the difference between the total amount of water and the hygroscopic coefficient—in those portions of the soil and the subsoil occupied by the roots (1, p. 121).[1] The hygroscopic coefficient (8, p. x; 10, p. 243) expresses the percentage of moisture contained in a soil which, in an air-dry condition, has been brought into a saturated atmosphere, kept at a constant temperature, and allowed to remain until in approximate equilibrium with this atmosphere.

Hilgard's method for the direct determination (10, p. 243; 11, p. 17) of the hygroscopic coefficient requires provision for the maintenance of a constant temperature in the room in which the absorption boxes are placed and also presents difficulties in insuring the actual saturation of the atmosphere in these boxes. Accordingly, any indirect method which gives results in satisfactory accord with those obtained by direct determination and at the same time requires only apparatus which is less inconvenient, either of installation or of operation, will prove useful.

Briggs and Shantz (7, p. 73) have recently proposed several indirect methods, and to the consideration of the reliability of one of these the present paper is devoted. These authors derived formulas for the indirect determination of what they designate the "wilting coefficient," defined as the moisture remaining in the soil in immediate contact with the roots when the permanent wilting of a plant occurs, from the moisture equivalent (6, p. 140; 4, p. 276), from the maximum water capacity as

[1] Reference is made by number to "Literature cited," p. 845.

defined by Hilgard (10, p. 256), and from the mechanical analysis. Subsidiary formulas for the indirect determination of the hygroscopic coefficient, following as a result of the interrelationships thus established, they report (7, p. 73) as follows:

$$\text{Hygroscopic coefficient} = \begin{cases} \text{Wilting coefficient} \times 0.68. \\ \text{Moisture equivalent} \times 0.37. \\ (\text{Maximum water capacity} - 21) \times 0.234. \\ (0.007 \text{ sand} + 0.082 \text{ silt} + 0.39 \text{ clay}). \end{cases}$$

As the mechanical analysis of a soil is a far more difficult and time-consuming operation than the determination of the hygroscopic coefficient, the latter could advantageously be calculated from the former only where this is already available, as, for example, in the reports of soil surveys. Even then there is a probability of introducting serious errors. Thus, with a series of loess soils (3, p. 411) it has recently been shown that the values for the hygroscopic coefficient calculated by the Briggs-Shantz formula agree satisfactorily with those obtained by direct determination only in the case of those samples which carry the smallest proportion of very fine sand. However, by altering the values assigned the sands there was obtained the following modified formula, which was found applicable to all the loess soils investigated.

Hygroscopic coefficient = 0.005 coarser fractions + 0.07 very fine sand + 0.82 silt + 0.39 clay.

"Coarser fractions" is here used to designate all soil particles having a diameter greater than 0.10 mm.

The wilting coefficient also is so inconvenient of determination that, unless it has to be determined for some other purpose, it will not be used to calculate the hygroscopic coefficient.

In connection with field studies of available soil moisture on the Nebraska loess, of which only a few data (1, p. 118) have as yet been published, one of us had arrived at conclusions so widely at variance with those of Briggs and Shantz, who, in somewhat similar studies, had employed the wilting coefficient, either determined directly or calculated from the moisture equivalent, that we suspected the explanation might lie in the differences in the values of the hygroscopic coefficient obtained for similar soils by our respective methods. However, as no moisture-equivalent apparatus was at that time available for our use we were unable then to decide the question. Now, using 135 samples of which hygroscopic coefficient determinations had been made at the Nebraska Experiment Station, we have determined the moisture equivalents, thus obtaining a definite answer to the question.

Lipman and Waynick (12) have recently reported both the moisture equivalents and the hygroscopic coefficients of 27 soils, and from these the ratios may be calculated. In so far as we are aware, there are no published data except those in the two articles mentioned from which the

relationship of the moisture equivalent to the hygroscopic coefficient can be computed.

COMPUTATIONS FROM DATA OF BRIGGS AND SHANTZ

Briggs and Shantz have reported (7, p. 57–65) both the hygroscopic coefficients and the moisture equivalents in the case of 17 soils ranging in texture from a coarse sand with a hygroscopic coefficient of 0.5 to a clay loam with a value of 13.2. Their data, however, were not presented in such form as to show the concordance of the hygroscopic coefficients calculated from the moisture equivalents with those directly determined, and for this reason we consider it desirable to so present them (Table I).

TABLE I.—*Relation of the moisture equivalent to the hygroscopic coefficient shown by data of Briggs and Shantz*[1]

Soil.	Type of soil.	Moisture equivalent.	Hygroscopic coefficient.	Ratio of moisture equivalent to hygroscopic coefficient.	Hygroscopic coefficient calculated from moisture equivalent.	Departure of calculated from determined hygroscopic coefficient.
7	Coarse sand	1.6	0.5	3.20	0.6	0.1
2	Fine sand	4.7	1.5	3.13	1.7	.2
8	....do	5.5	2.3	2.39	2.0	−.3
9	....do	6.7	2.3	2.91	2.5	.2
3	Sandy loam	9.7	3.5	2.77	3.6	.1
10	....do	11.9	4.4	2.70	4.4	.0
4	Fine sandy loam	18.1	6.5	2.78	6.7	.2
12	Loam	18.9	7.8	2.42	7.0	−.8
A	Sandy loam	19.6	6.3	3.11	7.2	.9
B	Fine sandy loam	19.9	6.6	3.01	7.3	.7
C	....do	22.1	7.5	2.94	8.2	.7
5	Loam	25.0	9.8	2.55	9.2	−.6
D	....do	27.0	9.6	2.81	10.0	.4
13	Clay loam	27.4	11.8	2.32	10.1	−1.7
14	....do	29.3	13.2	2.22	10.8	−2.4
E	....do	30.0	11.2	2.68	11.1	−.1
6	....do	30.2	11.4	2.65	11.2	−.2
	Mean[2]			2.71		
	Maximum			3.11		
	Minimum			2.22		

[1] Derived from Briggs and Shantz (7, p. 57, 60, 65, Tables XVII, XIX, and XX).
[2] Omitting 7 and 2.

Excepting the two sands, 1 and 2, the ratio varies from 3.11 to 2.22, a range of 40 per cent, reaching a maximum in the case of a sandy loam with a hygroscopic coefficient of 6.3 and a minimum in a clay loam with the coefficient 13.2. In the case of the latter the value calculated from the mean ratio, 2.71, differs by 2.4 from that obtained by direct determination. Two of the four clay-loam samples give concordant and two rather discordant results, the divergence in the case of the latter being similar to that obtained from the mechanical analysis of many of the loess soils (3, p. 411).

COMPUTATIONS FROM DATA OF LIPMAN AND WAYNICK

Lipman and Waynick report (12, p. 8–9) both the hygroscopic coefficients and the moisture equivalents on 27 samples used in the well-known so-called Tri-State Soil Exchange Experiment. The ratios, which evidently they did not compare, we show in Table II. These data have an added interest in that they are from the laboratory of the late Dr. Hilgard, who introduced the determination of the hygroscopic coefficient (8, 9, 10).

TABLE II.—*Relation of the moisture equivalent to the hygroscopic coefficient shown by the data of Lipman and Waynick*

HYGROSCOPIC COEFFICIENT [1]

Depth.	California soil.			Kansas soil.			Maryland soil.		
	In California.	In Kansas.	In Maryland.	In California.	In Kansas.	In Maryland.	In California.	In Kansas.	In Maryland.
Feet.									
1	8.55	8.29	6.68	12.12	10.74	11.00	5.97	5.15	4.69
2	8.67	7.69	8.44	12.42	12.38	11.68	6.82	5.82	7.66
3	8.98	8.68	9.04	11.28	10.54	11.18	8.87	6.75	9.23
Average	8.73	8.22	8.05	11.94	11.22	11.29	7.22	5.91	7.19

MOISTURE EQUIVALENT [2]

Depth.	In California.	In Kansas.	In Maryland.	In California.	In Kansas.	In Maryland.	In California.	In Kansas.	In Maryland.
1	24.09	22.32	22.67	32.61	29.63	29.80	23.62	23.67	21.92
2	22.81	22.20	20.32	33.33	30.78	31.14	24.26	26.02	19.37
3	24.02	24.24	23.53	30.21	27.57	29.40	29.17	29.16	27.38
Average	23.64	22.92	22.17	32.05	29.33	30.11	25.68	26.28	22.89

RATIO OF MOISTURE EQUIVALENT TO HYGROSCOPIC COEFFICIENT

Depth.	In California.	In Kansas.	In Maryland.	In California.	In Kansas.	In Maryland.	In California.	In Kansas.	In Maryland.
1	2.82	2.69	3.39	2.69	2.76	2.71	3.96	4.60	4.67
2	2.63	2.89	2.41	2.68	2.49	2.67	3.56	4.47	2.53
3	2.67	2.79	2.60	2.68	2.61	2.63	3.29	4.32	2.97
Average	2.71	2.79	2.80	2.68	2.62	2.67	3.60	4.46	3.39

[1] From Lipman and Waynick (12, p. 8, Table I). [2] From Lipman and Waynick (12, p. 9, Table II).

The average ratio for the 27 samples is 3.08, with a minimum of 2.41 and a maximum of 4.67, a range of 93 per cent. On inspection of Tables I and II it will be seen that for the Kansas soils the ratio varies only between 2.49 and 2.76, and for the California soils between 2.41 and 3.39, with an average for these 18 samples of 2.72, which is practically identical with the mean found by Briggs and Shantz—viz, 2.71.

In the case of the 9 samples of Maryland soils, the ratio varies from 2.53 to 4.67, with an average of 3.75. As none of the samples is to be considered lighter in texture than a loam or heavier than a clay loam, any ratio sufficiently accurate for ordinary purposes should apply to all of them.

EXPERIMENTAL WORK

The moisture equivalents were determined according to Briggs and Shantz (7, p. 57), bringing the soils into equilibrium with a force 1,000 times that of gravity, using a centrifuge (6, p. 141) made according to specifications kindly furnished by Dr. L. J. Briggs, of the Bureau of Plant Industry. The determination of the moisture equivalent has been found to be convenient of execution, and the results from day to day are very concordant.

In Table III are given the moisture equivalent, the hygroscopic coefficient, the ratio of these to one another, and the content of organic matter in 36 samples. The soils were collected from 30 virgin prairie fields in Nebraska, 5 near each of the six towns indicated in the table. All are from fields classified by the United States Bureau of Soils either as Marshall silt loams or as Colby silt loam. In each field 10 borings were made to a depth of 6 feet and composite samples prepared of each foot section, thus securing 6 samples from each field. From these were prepared the samples used in this work, equal weights of the corresponding 5 field samples being combined. The details of the method of sampling are reported elsewhere (2, p. 204). In the same article (2, p. 215) are given the hygroscopic coefficients for the foot sections from each of all the fields. Each value in B of Table III represents the average of 10 determinations. The data on the organic matter reported in D of the table were calculated from the organic carbon reported in the same article (2, p. 228; organic matter = C × 1.724). The data on the moisture equivalents are the means of duplicate determinations.

The ratio (Table III–C) averages 2.38, varying from 2.14 to 2.73, a quite similar, although somewhat narrower, range than that found by Briggs and Shantz. In general, in each area it is highest in the surface foot as though influenced by the proportion of the organic matter.

TABLE III.—*Moisture equivalent, hygroscopic coefficient, ratio of these two values, and organic-matter content of the foot sections from six different areas in Nebraska*

(A) MOISTURE EQUIVALENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
Feet.							
1	22.3	24.0	26.7	26.2	30.7	30.3	26.7
2	22.1	24.8	27.6	28.6	31.5	31.2	27.6
3	23.0	24.6	26.8	28.2	29.2	30.9	27.1
4	23.3	23.6	25.1	26.9	27.8	29.2	26.0
5	21.1	22.5	24.1	26.5	28.3	28.2	25.1
6	19.8	22.1	24.0	26.6	26.3	28.3	24.8
Average	21.9	23.6	25.7	27.2	29.3	29.7	26.2

(B) HYGROSCOPIC COEFFICIENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	9.1	10.0	10.1	9.6	12.0	12.1	10.5
2	9.6	10.9	11.2	11.6	14.4	13.7	11.9
3	9.7	10.7	11.3	12.4	13.6	13.9	11.9
4	9.9	9.7	10.2	11.1	13.0	13.0	11.1
5	9.0	9.1	9.6	10.7	12.8	12.6	10.6
6	8.3	9.1	9.4	10.7	12.7	12.5	10.5
Average	9.3	9.9	10.3	11.0	13.1	13.0	11.1

(C) RATIO OF MOISTURE EQUIVALENT TO HYGROSCOPIC COEFFICIENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	2.45	2.40	2.64	2.73	2.56	2.50	2.55
2	2.30	2.28	2.46	2.47	2.19	2.28	2.32
3	2.37	2.30	2.37	2.27	2.15	2.22	2.28
4	2.35	2.43	2.46	2.42	2.14	2.25	2.34
5	2.34	2.47	2.51	2.48	2.21	2.24	2.38
6	2.39	2.43	2.55	2.49	2.23	2.26	2.39
Average	2.37	2.38	2.50	2.48	2.25	2.29	2.38

(D) PERCENTAGE OF ORGANIC MATTER

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	2.77	2.85	3.90	3.55	4.96	4.98	3.83
2	1.38	1.44	1.86	1.81	2.28	3.02	1.96
3	1.09	.97	1.01	.98	1.14	1.38	1.09
4	.79	.59	.66	.60	.60	.83	.68
5	.55	.48	.41	.41	.43	.45	.45
6	.45	.36	.36	.31	.40	.36	.37
Average	1.17	1.11	1.37	1.28	1.63	1.84	1.40

Table IV shows the values for the hygroscopic coefficients calculated from the moisture equivalents, using the Briggs-Shantz formula, and the departure from those directly determined. In all cases the values are more or less too low; using these there might appear to be as much as from 1.0 to 2.8 per cent of free water in the case of a subsoil which actually carried none.

TABLE IV.—*The hygroscopic coefficients calculated from the moisture equivalents and the departure of these from the values obtained by direct determination*

(A) CALCULATED HYGROSCOPIC COEFFICIENTS

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
Feet.							
1	8.2	8.9	9.9	9.7	11.3	11.2	9.9
2	8.2	9.2	10.2	10.6	11.6	11.5	10.2
3	8.5	9.1	9.9	10.4	10.8	11.4	10.0
4	8.6	8.7	9.3	9.9	10.3	10.8	9.6
5	7.8	8.3	8.9	9.8	10.4	10.4	9.3
6	7.3	8.2	8.9	9.8	10.4	10.4	9.2
Average	8.1	8.7	9.5	10.0	10.8	11.0	9.7

(B) DEPARTURE FROM DIRECTLY DETERMINED VALUES

1	−0.9	−1.1	−0.2	−0.1	−0.7	−0.9	−0.6
2	−1.4	−1.7	−1.0	−1.0	−2.8	−2.2	−1.7
3	−1.2	−1.6	−1.4	−2.0	−2.8	−2.5	−1.9
4	−1.3	−1.0	− .9	−1.2	−2.7	−2.2	−1.5
5	−1.2	− .8	− .7	− .9	−2.4	−2.2	−1.3
6	−1.0	− .9	− .5	− .9	−2.3	−2.1	−1.3
Average	−1.2	−1.2	− .8	−1.0	−2.3	−2.0	−1.4

Table V gives similar data on another set of samples from the same 30 fields. These consisted of 1-inch sections from the surface foot (2, p. 206). In the case of these, however, each datum on hygroscopic coefficients as well as on moisture equivalents is the mean of only duplicate determinations. The ratio averages 2.75, compared with 2.71 found by Briggs and Shantz (Table I), and varies from 2.33 to 3.29, a range of 41 per cent, compared with 40 found by them with their 17 soils. Their samples also were probably surface soils rather than subsoils, such as predominate in Table III. In the inch sections, as in the foot sections, a decrease in the ratio is to be observed in passing from the surface to the subsoil. This may be attributed to the organic matter which appears to have a marked influence upon the moisture equivalent, although it shows little effect upon the hygroscopic coefficient (2, p. 217). Briggs and McLane (5, p. 18), found that organic matter had practically the same effect upon the moisture equivalent as an equal amount of clay.

TABLE V.—*Moisture equivalent, hygroscopic coefficient, ratio of these two values, and the organic content of the inch sections of the surface foot*

(A) MOISTURE EQUIVALENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
Inches.							
1	24.4	24.3	31.6	31.5	31.0	32.7	29.2
2	22.3	22.2	29.6	27.6	30.0	31.5	27.2
3	22.5	22.9	28.3	27.3	30.2	31.3	27.1
4	22.3	23.3	28.3	27.6	30.5	30.6	27.1
5	22.6	24.5	27.5	27.3	29.9	31.7	27.2
6	22.5	25.7	27.7	27.8	30.0	31.9	27.6
7	22.3	25.4	28.1	27.5	30.1	32.4	27.6
8	22.3	25.6	27.9	27.3	30.3	31.9	27.5
9	22.8	27.2	28.0	27.6	30.9	31.4	28.0
10	22.8	27.3	28.2	27.4	30.7	32.2	28.1
11	23.0	27.9	28.0	27.9	30.0	31.9	28.1
12	23.0	26.8	28.1	28.4	30.8	32.3	28.2
Average	22.7	25.2	28.4	27.9	30.4	31.8	27.7

(B) HYGROSCOPIC COEFFICIENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	8.5	8.5	10.9	10.9	11.5	11.5	10.3
2	8.2	8.3	10.3	9.7	11.2	11.0	9.8
3	8.2	8.4	9.9	8.9	11.0	11.0	9.6
4	8.3	8.3	9.5	8.5	11.1	11.1	9.5
5	8.2	8.7	9.4	8.3	11.4	11.2	9.5
6	8.6	9.3	9.4	9.0	11.8	11.2	9.9
7	8.7	9.5	9.7	9.5	11.9	11.5	10.1
8	8.8	9.8	9.9	9.5	12.1	12.1	10.4
9	8.6	9.9	10.0	9.5	13.0	12.3	10.6
10	8.8	10.3	10.4	9.7	12.6	12.6	10.7
11	9.0	10.3	10.2	10.0	12.9	12.5	10.8
12	8.7	10.2	10.2	10.2	13.1	12.8	10.9
Average	8.6	9.3	10.0	9.5	12.0	11.7	10.2

(C) RATIO OF MOISTURE EQUIVALENT TO HYGROSCOPIC COEFFICIENT

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
1	2.87	2.86	2.90	2.89	2.70	2.84	2.84
2	2.72	2.68	2.87	2.85	2.68	2.86	2.78
3	2.74	2.73	2.86	3.07	2.75	2.85	2.84
4	2.69	2.81	2.98	3.25	2.75	2.76	2.87
5	2.76	2.82	2.93	3.29	2.62	2.83	2.88
6	2.62	2.76	2.95	3.09	2.54	2.85	2.79
7	2.56	2.67	2.90	2.89	2.53	2.82	2.73
8	2.53	2.61	2.82	2.87	2.50	2.64	2.66
9	2.65	2.75	2.80	2.91	2.38	2.56	2.68
10	2.59	2.65	2.71	2.83	2.44	2.56	2.63
11	2.56	2.71	2.74	2.79	2.33	2.55	2.62
12	2.64	2.63	2.75	2.78	2.35	2.52	2.61
Average	2.66	2.72	2.85	2.96	2.55	2.72	2.74

TABLE V.—*Moisture equivalent, hygroscopic coefficient, ratio of these two values, and the organic content of the inch sections of the surface foot*—Continued.

(D) PERCENTAGE OF ORGANIC MATTER

Depth.	Wauneta.	McCook.	Holdrege.	Hastings.	Lincoln.	Weeping Water.	Average.
Inches.							
1	4.91	4.17	7.93	7.79	8.10	7.79	6.78
2	3.64	3.35	6.03	5.46	6.29	6.39	5.19
3	3.19	3.27	4.95	4.45	5.70	5.60	4.53
4	2.88	3.14	4.22	3.93	5.37	5.29	4.14
5	2.55	2.84	3.74	3.50	4.89	4.87	3.73
6	2.52	2.66	3.46	3.20	4.72	4.56	3.52
7	2.26	2.48	3.05	3.09	4.31	4.08	3.21
8	2.19	2.31	2.97	2.88	4.12	4.03	3.08
9	2.12	2.17	2.79	2.74	3.98	3.95	2.96
10	1.97	2.00	2.67	2.64	3.59	3.76	2.77
11	1.77	1.84	2.58	2.62	3.40	3.69	2.65
12	1.77	1.72	2.50	2.50	3.26	3.60	2.56
Average	2.67	2.69	3.90	3.72	4.77	4.81	3.76

The samples reported in Table VI are partly from the loess of Nebraska and partly from the residual soils of that State. A few are from New Mexico, Arizona, and California. The data upon both the hygroscopic coefficient and the moisture equivalent are the means of 5 to 10 concordant determinations. Nine of the samples are from the surface 6 to 12 inches, and the seven others from the subsoil. The range in texture represented by them is much the same as that of the soils reported by Briggs and Shantz (Table I).

TABLE VI.—*Relation of the moisture equivalent to the hygroscopic coefficient in a series of soils showing a wide range in texture*

Soil No.	Description of soil.	Moisture equivalent.	Hygroscopic coefficient.	Ratio of moisture equivalent to hygroscopic coefficient.	Hygroscopic coefficient calculated from moisture equivalent.[1]	Departure of calculated from found hygroscopic coefficient.
1	Desert sand, Palm Springs, Cal	1.6	0.9	1.77	0.6	−0.3
2	Sandy subsoil, Palm Springs, Cal	2.8	1.1	2.54	1.0	− .1
3	Desert sand, Orogrande, N. Mex	3.0	1.7	1.76	1.1	− .6
4	Sandy surface, W. Nebraska	7.9	3.3	2.39	2.9	− .4
5	Sandy subsoil (A), W. Nebraska	7.2	3.4	2.12	2.6	− .8
6	Sandy subsoil (B), W. Nebraska	7.5	3.4	2.21	2.8	− .6
7	Sandy loam subsoil, W. Nebraska	13.5	5.6	2.41	5.0	− .6
8	Sandy loam surface, W. Nebraska	16.8	7.1	2.37	6.2	− .9
9	Silt loam subsoil (A), W. Nebraska	19.7	7.6	2.59	7.3	− .3
10	Silt loam subsoil (B), W. Nebraska	21.2	8.2	2.59	7.8	− .4
11	Red loam surface, Cuervo, N. Mex	19.2	10.0	1.92	7.1	−2.9
12	Silt loam surface (A), W. Nebraska	22.5	10.1	2.23	8.3	−1.8
13	Silt loam surface, E. Nebraska	27.8	10.2	2.73	10.3	.1
14	Silt loam surface (B), W. Nebraska	24.1	10.5	2.30	8.9	−1.6
15	Adobe surface, McNeal, Ariz	25.8	12.0	2.00	9.6	3.3
16	Silt loam subsoil, E. Nebraska	29.5	13.3	2.22	10.9	−2.4

[1] Using Briggs and Shantz formula M. E. = hyg. coeff. × 2.71.

Excepting the two sands, 1 and 3, the average ratio of moisture equivalent to hygroscopic coefficient is 2.33, with a maximum of 2.73 and a minimum of 1.92. The lowest ratios are shown by the arid or semiarid soils, 1, 3, 11, and 15. The exceptional behavior of 11 and 15 is not to be attributed to error of determination, as, after finding these exceptional ratios, we made repeated determinations of both values. The ratios found for both subsoils and surface soils from Nebraska are quite similar to those reported in Table III, the average ratio, 2.38, being identical with that obtained for the 36 loess samples.

If the two sands, 1 and 3, in Table VI, be omitted, the variation of our ratios in Tables III, V, and VI are of much the same order as those of Briggs and Shantz, shown in Table I. Thus, the divergence in our conclusions as to the availability to plants of the portion of the soil moisture lying between the hygroscopic coefficient and the wilting coefficient is not to be explained by any differences in our respective methods of arriving at the value of the hygroscopic coefficient. Neither are there sufficient reasons to attribute it to the particular range of soils with which we have worked, for the data above show that our soils range as widely as those which they have employed.

Their data, as well as our own work, make it evident that in any accurate experiments to determine the relation of the nonavailable water of the soil to the hygroscopic coefficient it is not permissible to calculate the value of the latter from the moisture equivalent, unless a previous thorough investigation has been made to determine just what formula is applicable to the soil type in question. From the data of Lipman and Waynick it would appear that in the case of certain soils this indirect method would be scarcely allowable for even the crudest studies on soil moisture. However, in the case of any extensive study, involving many soil types, the same general conclusions as to the relation of the nonavailable moisture to the hygroscopic coefficient are to be expected, no matter whether the latter value be directly determined or be calculated from the moisture equivalent by the Briggs-Shantz or by some more satisfactory formula.

COMPUTATION OF THE MOISTURE EQUIVALENT FROM THE MECHANICAL ANALYSIS

Table VII shows the concordance of the moisture equivalents directly determined with the values computed from the mechanical analyses in the cases of the loess samples reported in Table III, using the formula proposed by Briggs and Shantz:

Moisture equivalent = 0.02 sands + 0.22 silt + 1.05 clay, and also a modified form of this formula:

Moisture equivalent = 0.14 sands + 0.27 silt + 0.53 clay. In these formulas "sands" include particles ranging from 2 to 0.05 mm. in diameter. The separates referred to in the table as "coarser fractions" include the particles ranging from 2 to 0.10 mm. It will be seen that the

formula of Briggs and Shantz gives values too low for the coarsest textured members of the series and too high for the finest textured. In the modified formula the value assigned to the clay is lowered, that to the "sands" much increased, and that to the silt slightly raised. This formula gives results in close concordance with the directly determined values. The explanation of the need of altering the values is not far to seek. As has already been pointed out in connection with the computation of the hygroscopic coefficients from the mechanical analyses of the same samples (3, p. 406), the material coarser than silt is chiefly very fine sand, consisting mainly of particles but little larger than the upper limit for silt, while the so-called "clay" contains a very large proportion of silt particles with a diameter not much less than 0.005 mm.

Briggs and McLane (5, p. 21), in applying their generalized formula based upon the analysis of 104 soils, found that for the Marshall series it was necessary to give the clay a lower value and also to make allowance for the content of organic matter. As has been mentioned above, the samples in Table VII belong to the Marshall and Colby series.

Thus, it appears that if the mechanical analyses are to be used for the computation of moisture equivalents, it will be necessary, at least in the case of some widely differing soil types, to employ several different formulas.

TABLE VII.—*Concordance of the values for the moisture equivalent obtained by computation from the mechanical analysis with those directly determined*

WAUNETA

Depth.	Coarser fract (2.0–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.005 mm.).	Clay (0.005–0.000 mm.).	Moisture equivalent. Determined.	Computed by formula. B. and S.[1]	Computed by formula. Mod.[2]	Departure, using formula. B. and S.	Departure, using formula. Mod.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*					
1	4.8	48.7	41.2	5.4	22.3	15.9	21.5	−5.4	−0.8
2	2.4	47.8	43.3	6.6	22.1	17.5	22.2	−4.6	.1
3	2.0	46.8	43.8	7.5	23.0	18.5	22.6	−4.5	−.4
4	1.7	47.6	41.3	9.5	23.3	20.1	23.1	−3.2	−.2
5	1.5	50.0	43.6	4.9	21.1	15.8	21.6	−5.3	.5
6	1.3	54.9	30.8	4.2	19.8	14.3	20.8	−5.5	1.0
Average	2.3	49.3	42.2	6.3	21.9	17.0	21.9	−4.9	0

M'COOK

Depth.	Coarser fract	Very fine sand	Silt	Clay	Determined.	B. and S.	Mod.	B. and S.	Mod.
1	3.7	39.0	48.6	8.7	24.0	20.7	23.7	−3.3	−0.3
2	2.6	37.8	50.1	9.5	24.8	21.8	24.2	−3.0	−.6
3	1.3	36.4	53.9	8.4	24.6	21.4	24.3	−3.2	−.3
4	1.4	38.9	52.4	7.4	23.6	20.0	23.7	−3.6	.1
5	1.8	39.3	52.6	6.3	22.5	19.0	23.3	−3.5	.8
6	1.2	40.4	51.8	6.6	22.1	19.2	23.3	−2.9	1.2
Average	2.0	38.6	51.6	7.8	23.6	20.4	23.7	−3.2	.1

[1] Moisture equivalent = 0.02 sands + 0.22 silt + 1.05 clay.

[2] Moisture equivalent = 0.14 sands + 0.27 silt + 0.53 clay.

TABLE VII.—*Concordance of the values for the moisture equivalent obtained by computation from the mechanical analysis with those directly determined*—Continued.

Depth.	Coarser fract (2.1–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.005 mm.).	Clay (0.005–0.000 mm.).	Moisture equivalent. Determined.	Computed by formula. B. and S.	Computed by formula. Mod.	Departure, using formula. B. and S.	Departure, using formula. Mod.
				HOLDREGE					
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*					
1	2.8	25.9	64.6	6.7	26.7	21.8	25.0	−4.9	−1.7
2	1.3	24.6	62.9	11.6	27.6	26.1	26.5	−1.5	−1.2
3	.8	26.5	62.5	10.5	26.8	25.3	26.2	−1.5	− .6
4	.9	27.8	64.8	6.4	25.1	21.6	24.9	−3.5	− .2
5	2.5	31.7	60.0	5.8	24.1	20.0	24.1	−4.1	.0
6	2.4	31.1	60.7	5.8	24.0	20.1	24.2	−3.9	.2
Average	1.8	27.9	62.6	7.7	25.7	22.5	25.1	−3.2	− .6
				HASTINGS					
1	3.9	23.9	64.6	7.6	26.2	22.8	25.4	−3.4	−0.8
2	2.7	20.3	64.5	12.5	28.6	27.8	27.3	− .8	−1.5
3	2.3	22.2	61.9	13.6	28.2	28.4	27.4	.2	− .8
4	2.1	21.5	62.4	14.0	26.9	28.9	27.6	2.0	.7
5	2.4	20.9	66.7	10.0	26.5	25.6	26.6	− .9	.1
6	2.2	20.7	67.2	9.9	26.6	25.6	26.6	−1.0	0
Average	2.6	21.6	64.5	11.3	27.2	26.5	26.8	−0.7	−0.4
				LINCOLN					
1	3.8	13.5	68.0	14.8	30.7	30.8	28.6	0.1	−2.1
2	3.7	9.8	67.6	18.9	31.5	35.0	30.2	3.5	−1.3
3	3.4	9.3	68.0	19.3	29.2	35.5	30.4	6.3	1.2
4	3.2	9.6	68.1	18.9	27.8	35.1	30.2	7.3	2.4
5	3.7	9.9	69.4	17.0	28.3	33.4	29.7	5.1	1.4
6	3.9	9.5	70.2	16.5	28.3	33.0	29.6	4.7	1.5
Average	3.6	10.3	68.5	17.6	29.3	33.8	29.8	4.5	.5
				WEEPING WATER					
1	4.2	9.7	72.2	13.9	30.3	30.8	28.8	0.5	−1.5
2	2.8	8.2	69.5	19.6	31.2	36.1	30.7	4.9	− .5
3	1.0	13.8	66.7	18.6	30.9	34.5	29.9	3.6	−1.0
4	.6	14.9	67.0	17.6	29.2	33.5	29.6	4.3	.4
5	.5	14.7	67.9	17.0	28.2	33.1	29.5	4.9	1.3
6	.5	15.0	67.5	17.1	28.3	33.1	29.5	4.8	1.2
Average	1.7	12.7	68.5	17.3	29.7	33.5	29.7	3.8	0
Average of all	2.3	26.7	59.7	11.3	26.2	25.6	26.2	−0.6	0

SUMMARY

The hygroscopic coefficient may in most cases be calculated from the moisture equivalent with sufficient accuracy to permit its use in soil-moisture studies. For certain types of soil, however, the ratio departs so widely from that assigned by Briggs and Shantz that the indiscriminate use of the latter value does not seem permissible. Before employing this indirect method for the determination of the hygroscopic coefficient in connection with soil-moisture studies the ratio should be experimentally established for each of the particular types of soil involved.

The effect of considerable quantities of organic matter is, in general, to give the ratio of the moisture equivalent to the hygroscopic coefficient a higher value.

In the case of any extensive study of soil moisture involving many soil types the same general conclusions as to the relation of the non-available moisture to the hygroscopic coefficient are to be expected no matter whether the latter value be directly determined or be calculated from the moisture equivalent by the Briggs-Shantz formula.

For the calculation of the moisture equivalent from the mechanical analysis no general formula appears universally applicable, the formula needing modification according to the soil type to which it is to be applied.

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THERSILOCHUS CONOTRACHELI, A PARASITE OF THE PLUM CURCULIO

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INTRODUCTION

During the seasons of 1914 and 1915 the ichneumonid *Thersilochus conotracheli* Riley (Pl. CIX) has been by far the most abundant and effective parasite of the plum curculio at North East, Pa. In 1914 a very large percentage of the fruit on a few plum trees (*Prunus* spp.) that stand on the premises of the Bureau of Entomology laboratory at that place was infested by the curculio. In the spring the adults of the parasite were abundant on these trees and parasitized a large percentage of the curculio larvæ in fruit that was still on the trees when the parasites became active.

Under date of June 13, 1914, the writer's notes contain the following:

Very few of the larvæ of this species have been found in host larvæ more than one-eighth inch long, although many of larger size than this have been examined. This indicates that the parasite does not begin oviposition until some time after the curculio has begun its attack on the fruit, and therefore does not exercise any control over the early curculio larvæ.

The season of 1915 found the curculio much reduced in numbers. The cold, wet season, however, retarded the emergence of the parasites to such an extent that they attacked only the latest of the larvæ, practically all of these being parasitized.

HISTORICAL REVIEW

The first mention of *Thersilochus conotracheli* in literature appeared in 1871, when Riley (1)[1] published his original description of the species, referring it to the genus Porizon, and recorded it as a parasite of the plum curculio (*Conotrachelus nenuphar* Herbst) in New Jersey. Riley (2, p. 18) again referred to it in a paper written in German and published in St. Louis. In 1880 Gott (3, p. 57) reported that in his work with the plum curculio in Canada he had not found this parasite. Riley and Howard (4, p. 63–64) in 1889 referred the species to the genus Thersilochus, gave a brief life history, and recorded the species as nearly as

[1] Reference is made by number to "Literature cited," p. 855.

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abundant in some sections as *Sigalphus curculionis* Fitch. Thereafter until 1906 there were published apparently only two references to the species; one by Riley and Howard (5), which is a repetition of the original breeding record, and one by Harrington (6, p. 67), in which the insect is merely mentioned as a parasite of the plum curculio. In 1906 Johnson and Girault (7, p. 6) mentioned this insect in the account of their work on the plum curculio in New York, and accorded it small importance in the control of its host. Quaintance and Jenne (8, p. 147–148) in 1912 gave a résumé of previously published accounts, together with data on the abundance and emergence of adults in spring in New York and Pennsylvania. As showing the distribution of the species these authors list the following States: New York, New Jersey, Connecticut, Illinois, Missouri, and Kansas.

HOSTS AND DISTRIBUTION

So far as is known the plum curculio is the only insect attacked by this species, published records showing it to have been reared from this host in Connecticut, New York, New Jersey, Pennsylvania, Illinois, Missouri, and Kansas. In addition to these States the writer has had material from Michigan.

LIFE HISTORY OF THE SPECIES

GENERATIONS

This species is single-brooded, the life cycle of one generation embracing the whole year. The adult stage is reached in the fall, but the perfect insect does not leave its cocoon until the following spring.

EMERGENCE OF ADULTS

The adult *T. conotracheli* emerges from its cocoon from late May to the middle of June and very shortly begins the search for hosts.

RELATIVE ABUNDANCE AND TIME OF EMERGENCE OF SEXES

The males begin to appear a few days ahead of the females, and the latter continue to emerge long after the last male. A lot of cocoons collected by the late A. G. Hammar at Douglas, Mich., in the spring of 1911 and reared by the writer at Vienna, Va., produced adults as indicated in Table I. This table shows the date and period of emergence, the comparative dates of emergence of males and females, and the proportion of the sexes.

TABLE I.—*Emergence of adults of Thersilochus conotracheli from cocoons collected at Douglas, Mich., and reared at Vienna, Va., in 1911*

No.	Date emerged.	Males.	Females.
1	May 22	2	....
2	23	1	....
4	25	14	....
6	27	11	1
7	28	1	2
8	29	1	2
9	30	2	2
10	31	2	8
11	June 1	3	6
12	2	1	3
13	3	....	2
15	5	....	11
16	6	....	5
18	8	....	3
19	9	....	3
22	12	....	3
24	14	....	2
27	17	....	1
28	18	....	1
29	19	....	1
30	20	....	1
32	22	....	1
33	23	....	1
35	25	....	1
37	27	....	1
Total		38	61
Average date of emergence		May 27	June 7
Percentage of sexes		38.39	61.61

LONGEVITY OF THE ADULT

Some data on the longevity of the adult were obtained in 1911 from specimens reared at Vienna, Va., from the cocoons collected by Mr. Hammar at Douglas, Mich. Only females were used. Ten of these were divided into three lots, as follows: Four were placed in vials without food or water, three with water, and three with dilute sugar sirup. Of those without food or water one lived 4 days, two lived 3 days, and one lived 1 day. One of those provided with water lived 7 days, one 6 days, and one 4 days. Those fed with sirup lived 10 days, 13 days, and 15 days. The confinement in the vials undoubtedly shortened the life, even of the sirup-fed specimens, but the figures show the necessity for both food and water; for those given clear water lived, on the average, more than twice as long as those without food or water, and those provided with sirup lived more than four and one-half times as long.

STAGE OF HOST ATTACKED

Parasitization takes place while the curculio larva is still very small, probably from the time it hatches until in its burrowing into the fruit it gets beyond the reach of the ovipositor of the parasite.

EFFECT OF PARASITISM ON HOST

Beyond possibly a temporary inactive condition induced by the sting, the oviposition by the parasite does not seem to injure the host. But shortly after the newly hatched larva begins to feed, the character of the body contents shows a considerable change. The adipose tissue loses its flocculent character and becomes a more homogeneous, more fluid mass, diluted by the blood. This same change in the host was noted by Timberlake (9) in his studies of *Limnerium validum* Cresson.

Parasitized larvæ at the time they leave the fruit are, as a rule, much smaller than healthy larvæ, although parasites have been found in hosts of nearly normal size. Whether this smaller size is due to the failure of the host to grow normally or to its failure to pass through all of its stages is a question which has not been determined.

OVIPOSITION

In oviposition the female parasite, having found a curculio oviposition scar, raises her abdomen, at the same time releasing the ovipositor from its sheath and, directing it forward between her legs, thrusts it into the tunnel made by the curculio larva. If she can reach the larva, she pierces its skin and deposits within it a single egg. The act of oviposition is very brief, the longest observed having required about two minutes.

The female *T. conotracheli* has been observed repeatedly in the cages to attempt oviposition or rather to probe for possible hosts in abrasions of any sort in the skin of the plums provided. This apparently indicates that she can not recognize infallibly the typical scar made by the curculio in oviposition.

INCUBATION PERIOD

No exact data on the incubation period are available, but that it is very short is indicated by the fact that in the many young larvæ examined in the course of the observations only one egg was found within a host, although they are very easily discovered. At the same time that the above-mentioned egg was discovered, another curculio larva, which had not traversed more than half an inch within the fruit, was found to contain a very young parasite larva. This also would indicate a short incubation period. A curculio larva exposed in a cage for one day, July 1–2, 1915, to the attack of *T. conotracheli* and dissected on July 7 was found to contain a very young larva of the parasite. This would indicate a maximum incubation period of six days, although it may have been even shorter than that.

THE LARVA

POSITION IN RELATION TO HOST.—Throughout most of the larval life this species lives as an internal parasite, the larval parasite lying free within the body cavity of its host. When nearly full grown, however, it leaves the host and becomes temporarily an external feeder, draining from without the last trace of fluid from the body of its victim.

FEEDING PERIOD.—Because of the impossibility of following an individual parasite throughout its development, the determination of the exact duration of the various larval instars is very difficult and must be based on the average of many individuals. During this period of its life the larva molts four times. Larvæ of the first instar are to be found within curculio larvæ even as long as three days after the latter have finished feeding and entered the ground. In fact, it seems to be the rule that the first larval molt of the parasite takes place after the host has constructed its pupal cell. Apparently, however, this is not invariably true, since larvæ as old as the third instar have been removed from their hosts within three days of the time the latter entered the ground. Thereafter the development of the parasite is very rapid, for within 10 days it passes through its second, third, and fourth instars, and in some cases has left the body of its host and has begun the construction of its cocoon.

DESTRUCTION OF SUPERNUMERARY LARVÆ.

Repeatedly in the dissection of the parasitized curculio larvæ more than one, sometimes several, first-instar larvæ of *T. conotracheli* have been found in a single host. Invariably, however, only one of these was in a healthy condition. The others were mostly dead and more or less inclosed in a mass of cells in the manner described by Timberlake (9, p. 75–76), and shown by him to be amebocytosis. In one case a still living but unhealthy larva partially inclosed by amebocytes was found in a curculio larva that also contained one healthy larva and two dead and completely invested larvæ. In no case, however, have all of the parasites been dead. Apparently the death of the parasite larvæ is not due to any protective adaptation on the part of the host, as suggested by Timberlake (9), for parasites in strange host species; for, as stated above, in no case were all larvæ killed, and in no case where but one egg was deposited within a host was the parasitism unsuccessful. The only source, therefore, of the destructive agency, whatever its nature, must lie within the surviving parasite larva. No explanation as to the nature of this agency is possible at this time.

THE COCOON

The cocoon of *T. conotracheli* (fig. 1) is about 5 mm. long by about half as thick and oval in shape. It is constructed of tough reddish-brown silk.

FIG. 1.—*Thersilochus conotracheli:* Cocoon. Much enlarged.

PUPATION AND TRANSFORMATION

About four or five days after the construction of the cocoon pupation takes place. When the transformation to the adult condition takes place was not determined by the present writer, but according to Quaintance and Jenne (8, p. 147–148) Mr. Fred Johnson found adults in cocoons at Youngstown, N. Y., in 1908, as early as August 24. As indicated above, the species hibernates in this condition within the cocoon.

DESCRIPTION OF THE IMMATURE STAGES

THE EGG

The egg (fig. 2) is oblong oval in shape, somewhat larger at the cephalic end, about 0.33 mm. in length by a little more than a fourth as wide, and slightly curved. A magnification of 215 diameters showed no sculpture of the chorion.

FIG. 2.—*Thersilochus conotracheli:* Egg. Highly magnified.

THE LARVA

FIRST INSTAR.—The newly hatched larva (fig. 3) resembles in general appearance that of *Limnerium validum* as figured by Timberlake (9, p. 84).

The body consists of 13 segments, including the head and the long taillike caudal segment. The head is somewhat more than half as long as the rest of the body exclusive of the tail, which is somewhat longer than the head. The head is bent slightly downward from the general axis of the body. It is heavily chitinized and pale brown in color, considerably longer than wide, and strongly curved above so that the mouth opening is on the underside. The mouth parts consist of the heavily chitinized, acute, curved mandibles and the very delicate labrum, maxillæ, and labium. The exact form of the last three appendages is very difficult to ascertain with exactness, but they seem to be arranged about as in figure 4. The mandibles are very distinct even well within the head cavity, although their place of attachment is not clear. Ap-

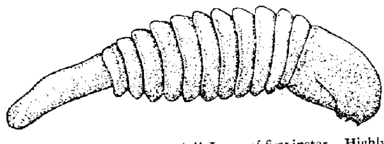

FIG. 3.—*Thersilochus conotracheli:* Larva of first instar. Highly magnified.

parently they are attached very close together at a point above the labium. During its first instar the larva undergoes a comparatively enormous increase in size, becoming ultimately 2 mm. in length and much distended, only the head and taillike appendage retaining their original dimensions. The approximate appearance of the parasite at this period of its development is shown in figure 5.

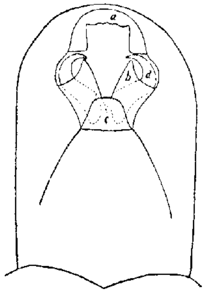

FIG. 4.—*Thersilochus conotracheli:* Ventral surface of head of first larval instar: *a*, Labrum; *b*, maxilla; *c*, labium; *d*, mandible. Highly magnified.

SECOND INSTAR.—With its first molt the larva acquires an entirely different appearance. The first larval skin splits longitudinally just back of the head and the forward part of the body is drawn out. Then the skin is pushed off from the caudal end of the body. The head shield remains intact. The larva that emerges lacks the taillike appendage and the prominent, heavily chitinized head. Its mouth parts are apparently entirely soft, and the most careful preparation and mounting of specimens has failed to disclose any mandibles. The mouth has the appearance of a dimplelike depression without armature. At full growth this instar (fig. 6) is about 3 mm. long. The head measures 0.31 mm. broad.

FIG. 5.—*Thersilochus conotracheli:* Full grown larva of the first instar. Highly magnified.

THIRD INSTAR.—The third instar is very like the second, except that it is larger, slightly stouter, and the head is 0.38 mm. broad. This measurement constitutes the only infallible distinction between the two stages. At full growth the third instar is about 3.50 mm. long.

FOURTH INSTAR.—With the assumption of the fourth instar the larva acquires the typical ichneumonoid larval characteristics. It is now in the form of a curved spindle, thick in the middle and tapering toward each end. It is about 4 mm. long with the head nearly a half millimeter broad, and with fairly distinct mouth parts. With high magnification the labrum, mandibles, maxillæ, and labium can be distinguished as well as the maxillary and labial palpi. The palpi appear merely as low rounded elevations on the surface of the maxillæ and labium. The mandibles are cone-shaped, and somewhat drawn out to

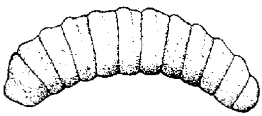

FIG. 6.—*Thersilochus conotracheli:* Larva of second instar. Greatly enlarged.

an acute, fairly strongly chitinized point. They are about 0.06 mm. long. The fourth molt takes place when the larva is about 4.75 mm. long.

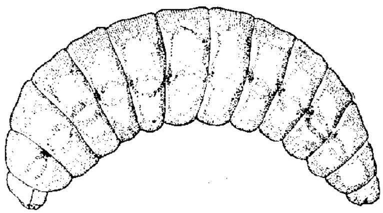

Fig. 7.—*Thersilochus conotracheli:* Full-grown larva, or fifth instar. Much enlarged.

FIFTH INSTAR.—The fifth instar (fig. 7) is a somewhat enlarged replica of the fourth, with the mandibles and other mouth parts more heavily chitinized and somewhat larger. The mandibles are of nearly the same form as those of the fourth instar, but are about 0.074 mm. in length. In this instar also the ridges supporting the mouth parts are strongly chitinized and can be faintly seen through the skin, especially the one extending from the base of the mandible around to the sides of the head. (See fig. 8.) Immediately after the molt this instar is about 5 mm. long, and at full growth, after it has left the body of its host and entirely consumed the fluid contents, it has reached a length of about 7 mm.

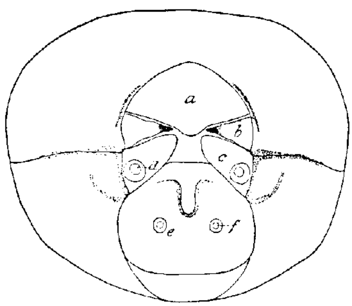

FIG. 8.—*Thersilochus conotracheli:* Face of full-grown larva: *a*, Labrum; *b*, mandible; *c*, maxilla; *d*, maxillary palpus; *e*, labium; *f*, labial palpus. Highly magnified.

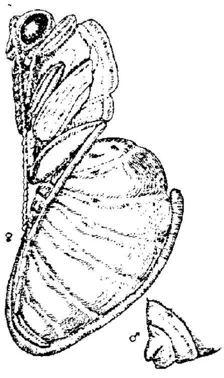

FIG. 9.—*Thersilochus conotracheli:* Pupa of female, and apex of abdomen of male pupa. Much enlarged.

THE PUPA

The pupa (fig. 9) is stout, about 4.5 mm. long, and in the female has the ovipositor curved up over the back and reaching about two-thirds of the way to the thorax. The abdomen is about two-thirds as deep as long and is much stouter than and nearly twice as long as the thorax. The thorax is blocky, with the rather small head situated near the ventral anterior margin. The antennæ reach to about the middle of the abdomen and the hind legs nearly to the apex. The abdomen of the male pupa is terminated by three lobes, one dorsal and two ventral, the latter representing the genital armature of the adult.

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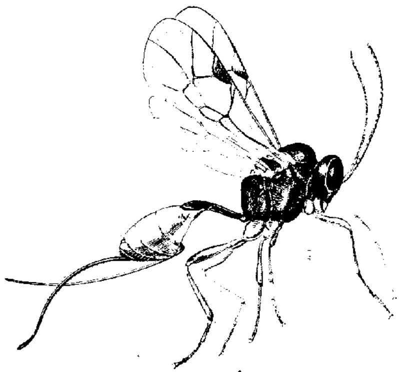
PLATE CIX

Thersilochus conotracheli

Fig. 1.—Adult female. Greatly enlarged.

Fig. 2.—*a*, Adult male; *b*, side view of abdomen. Greatly enlarged.



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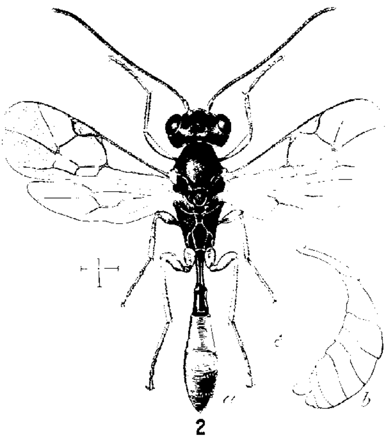

2

EFFECT ON PLANT GROWTH OF SODIUM SALTS IN THE SOIL

By FRANK B. HEADLEY, *Superintendent, Truckee-Carson Field Station*, E. W. CURTIS, *Scientific Assistant, and* C. S. SCOFIELD, *Agriculturist in Charge, Office of Western Irrigation Agriculture, Bureau of Plant Industry*

INTRODUCTION

In connection with an attempt to utilize for crop production certain salty land on the Truckee-Carson Field Station, at Fallon, Nev., it has been necessary to make numerous determinations as to the limit of the salt content of the soil tolerated by crop plants. These determinations have shown that this limit of tolerance is not a fixed and definite point, but is instead extremely variable. Not only is it influenced by many factors, such as kind of soil, kind of salt, and kind of plant, but the same crop plant shows marked differences in tolerance at different periods of its growth. These facts make the problem of dealing efficiently with the reclamation of alkali land a very complex one.[1]

In the present instance the more abundant and deleterious salts are those of sodium. These sodium salts occur as carbonates, bicarbonates, chlorids, and sulphates, and the proportions of each in different parts of the field are extremely variable. This variability of the proportions in which these salts occur confused the results of the early attempts to determine the limits of tolerance for the different crops. In order to establish a basis from which to proceed with the work, a series of pot cultures was carried on in which the soils were artificially impregnated with solutions of the different salts. These experiments have served to show the limit of tolerance to each of the four salts of one crop, wheat, in the seedling stage. They have also brought out a point which has not generally been taken into account in similar experiments—that the limit of tolerance of plants is dependent not upon the quantity of salt added to the soil but upon the quantity which exists in the soil solution and which is recoverable from the soil by water digestion.

It appears that the discrepancy between the amount of salt added to a soil and the amount which can be later recovered from it is sometimes very great. Different soils show different results in this respect; and some of the salts, particularly the carbonates and sulphates of sodium, are absorbed by the soil to a greater extent than sodium chlorid. Thus, if the limit of tolerance of a plant is given in terms of the quantity of salt which must be added to a soil to inhibit growth, this limit will be found

[1] For literature germane to this subject see Harris, F. S. Effect of alkali salts in soils on the germination and growth of crops. *In* Jour. Agr. Research, v. 5, no. 1, p. 1-53. 1915.

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to differ from one given in terms of the salt recoverable from the same soil. In actual field practice salt lands must be classified in terms of the amount of salt recoverable from them and not in terms of the amount which has been added to them, which is not ascertainable.

PLAN OF THE EXPERIMENTS

The general plan of all of the experiments was as follows: Ordinary drinking glasses were filled with 300 gm. of air-dry soil. The salts were added from a stock solution of known strength and ranged in amount from nothing up to concentrations sufficiently strong to prevent plant growth entirely. Distilled water was added to each glass to moisten the soil thoroughly. Seven seeds of wheat (*Triticum* spp.) were planted in each glass, and after germination the number of plants was reduced to five if more than that number came up. Bluestem wheat was used in 1913 and 1914, and Marquis wheat in 1915. To prevent loss of moisture, the glasses were covered with glass plates until the plants emerged. After the emergence of the plants, the pots were weighed daily, and by the addition of distilled water the moisture content was brought back to the original condition. In 1913 and 1914 the experiments were conducted in triplicate, while in 1915 they were in duplicate.

The wheat was allowed to grow from 15 to 18 days, when the plants were cut at the surface of the ground and weighed immediately in a closed tube. After cutting the plants the soils from each series of glasses were mixed, dried, and analyzed for water-soluble salts.

CONVERSION OF CARBONATES

In the experiments where sodium carbonate was added to the soil, the analysis of the soil after the wheat had been cut brought out the fact that a portion of the sodium carbonate that had been added was not recoverable.

When only a small quantity of sodium carbonate was added, none could be recovered at the end of the experiment, but the quantity of sodium bicarbonate was greater than in the untreated soil. With the addition of larger quantities of sodium carbonate both salts were recovered at the end of the experiment, but their sum was always less than the quantity added at the beginning.

It is apparent that a portion of the sodium carbonate added to the soil was converted into sodium bicarbonate. In order to determine what proportion of the original quantity of sodium carbonate could be accounted for at the end of the experiment, it was necessary to add together the quantity of sodium carbonate recovered as such and the quantity represented in the form of sodium bicarbonate.

The conversion of sodium carbonate to sodium bicarbonate results in an increase in weight of the salt at the ratio of 44 to 70—that is, the

weight of a quantity of sodium carbonate is 63 per cent of the weight of the sodium bicarbonate that could be formed from it.

In the following tables and discussions the sum of the sodium carbonate and 63 per cent of the sodium bicarbonate found in the soil solution have been designated as "carbonate salts."

EFFECT OF SODIUM CARBONATE ON WHEAT SEEDLINGS

EXPERIMENT 1.—The soil used in this experiment was obtained on the farm of the Truckee-Carson Field Station. It would be classed as a fairly productive sandy loam. It was analyzed for alkali salts and found to contain but a small quantity. The samples were made up in triplicate and sodium carbonate in solution was added to each set in the following percentages to the dry weight of the soil: Series 1, no treatment; series 2, 0.05; 3, 0.10; 4, 0.15; 5, 0.20; 6, 0.25; 7, 0.30; 8, 0.35; 9, 0.40; 10, 0.45; 11, 0.50; 12, 0.60.

Wheat was planted on November 1, 1913, and cut and weighed on December 11. Because of the lateness of the season, the growth had been very slow. After the wheat seedlings were removed, the soil from each set of pots was composited for analysis. The analysis was made of the solution secured by thorough digestion with an excess of water. The condensed results of this experiment are given in Table I.

TABLE I.—*Results of experiment 1 (1913), giving the quantity of sodium carbonate added to the soil, the quantity finally recovered as carbonates, the number of plants, and the combined weight produced in each case*

Series No.	Sodium carbonate.		Sodium bicarbonate recovered from soil.[1]	Total carbonate salts recovered.	Number of plants.	Green weight of plants.				Decrease in yield from check pot.
	Added to soil.	Recovered from soil.				Pot 1.	Pot 2.	Pot 3.	Total.	
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Per ct.*
1	0	0	0	0	15	0.973	1.009	0.937	2.919	.....
2	.05	0	.02	.013	15	.978	.950	.974	2.902	0
3	.10	Trace.	.04	.025	15	.697	.865	.847	2.409	17
4	.15	.02	.04	.045	13	.619	.061	.116	.796	73
5	.20	.03	.05	.062	10	.220	.055	.044	.319	89
6	.25	.07	.05	.102	5	.008	.012	.020	.040	98.7
7	.30	.11	.02	.123	1	0	.008	0	.008	99.7
8	.35	......	......	......	0	0	0	0	0	100

[1] In excess of sodium bicarbonate present at beginning of experiment.

This experiment showed that where more than 0.30 per cent of sodium carbonate was added to the soil no plant growth was obtained; therefore the analyses of the higher percentages have not been included in Table I. The addition of 0.15 per cent of the salt reduced the germination of the seed, so that the full number of plants was not obtained and the total green weight produced was 73 per cent below that of the check series.

Beyond this critical point the reduction of germination and growth was rapid and consistent.

The experiment also showed that the quantity of sodium carbonate recoverable at the end of the experiment was much less than had been added to the soil at the beginning. The quantity of sodium bicarbonate had been increased in every case, but the total carbonate salts recovered was much less than had been added.

The apparent loss of the sodium carbonate added to the soil is shown in the difference between the figures in columns 2 and 5 of the table. The data of Table I are shown graphically in figure 1.

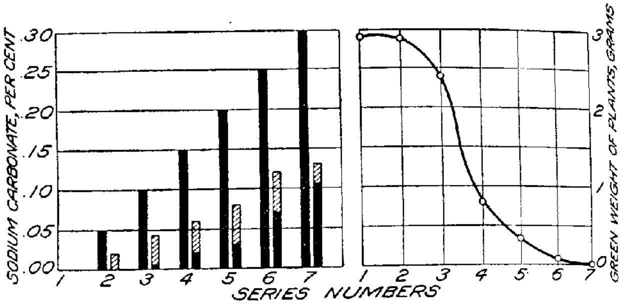

FIG. 1.—Diagram of the percentage of sodium carbonate added to the soil in experiment 1 (1913), with the percentage of carbonate and bicarbonate recovered and the total green weight of wheat obtained. The solid black line on the left at each series number indicates the percentage of sodium carbonate added to the soil; the line at the right shows the percentage recovered at the end of the experiment. The solid portion of the line shows the carbonate and the hatched portion the bicarbonate. The curve at the right of the figure shows the relative growth of the plants in each series of pots.

EXPERIMENT 2.—The experiment was in most respects a repetition of experiment 1. The soil used was also taken from the same farm and was of the same physical character, but had been made more productive by the use of farm manure on the field from which it was taken. A preliminary analysis of this soil gave the following results: Sodium carbonate, 0; sodium bicarbonate, 0.091 per cent; sodium chlorid, 0.006 per cent; sodium sulphate, 0.

A triplicate series of sample pots were made up as before and sodium carbonate in solution was added as shown in Table II.

The wheat was planted in the pots on September 22, 1914, and cut and weighed on October 5. It was noted that with the successive increases in the percentage of carbonate added the time required for germination was increased, the percentage of germination decreased, and the amount of growth, both of leaves and roots, decreased. The results of this experiment are summarized in Table II.

TABLE II.—*Results of experiment 2 (1914), giving the quantity of sodium carbonate added to the soil, the quantity finally recovered as carbonates, the number of plants, and the combined weight produced in each case*

Series No.	Sodium carbonate.		Sodium bicarbonate recovered from soil.[1]	Total carbonate salts recovered.	Number of plants.	Green weight of plants.				Decrease in yield from check pot.
	Added to soil.	Recovered from soil.				Pot 1.	Pot 2.	Pot 3.	Total.	
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Per ct.*
1	0	0	0	0	15	1.013	0.951	1.102	3.066	0
2	.05	0	0	0	15	1.025	.966	.778	2.769	10
3	.10	0	.03	.019	12	.697	.776	.554	2.027	33
4	.15	.02	.03	.039	11	.551	.680	.450	1.681	45
5	.20	.03	.03	.049	6	.450	.127	.327	.904	71
6	.25	.04	.04	.065	6	.064	.115	.281	.460	85
7	.30	.06	.04	.085	3	.028	0	.145	.173	94
8	.35	.07	.05	.102	3	.044	0	.273	.317	90
9	.40	.12	.03	.139	1	.020	0	.059	.079	97.5

[1] In excess of sodium bicarbonate present at beginning of experiment.

The results of experiment 2 are in close accord with those of No. 1, although the decrease in yield was not quite so rapid. The apparent loss of carbonates—that is, the difference between the amount added and that recovered—was slightly greater. It is noticeable that in both experiments the percentage of sodium bicarbonate recoverable did not increase materially with the percentage of carbonate added, while there was a fairly consistent increase in the percentage of carbonate recovered. Furthermore, it will be observed that the decrease in yield follows the increase in total carbonates recovered more closely than the increase in carbonate added to the soil.

The results of experiment 2 are shown graphically in figure 2, in which the same arrangement of symbols is used as in figure 1.

EXPERIMENT 3.—This experiment was undertaken for the purpose of comparing the toxic effect of sodium carbonate on the growth of wheat seedlings in two very different types of soil. The first of these was a rich loam soil from an old alfalfa field on the Truckee-Carson Irrigation Project, and the second was beach sand obtained from Monterey, Cal. The experiment was conducted in the summer of 1915. Duplicate sets of pots were used in each case. After the salt had been added to the pots, the moisture content was kept at 12 per cent in the sand and 15 per cent in the loam. This arrangement had the disadvantage of making the concentration of the soil solution different in the two soils, but it was considered necessary because 15 per cent of moisture in the sand would have kept it too wet, and less than 15 per cent in the loam soil would not have been sufficient for the best growth of the plants.

The difference in the effect of the carbonate in the two soils was evident in a very few days. The time required for the wheat to emerge was approximately the same in both cases, but in the sand all germination was stopped by the addition of 0.20 per cent of sodium carbonate, whereas it required the addition of 0.50 per cent to the loam to have the same effect. The carbonate had a very detrimental effect on the physical condition of the loam soil, causing a stiff crust to form on the top of the pots, the crust becoming more noticeable with the increase of the percentage of carbonate. This made it difficult for the plants to break through. The detailed results of the experiment with loam and sand soils are given in Table III.

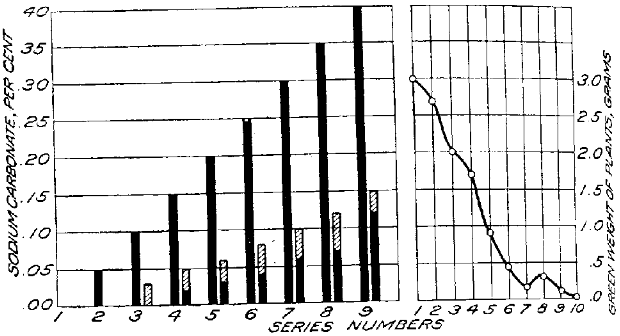

FIG. 2.—Diagram of the percentage of sodium carbonate added to the soil in experiment 2 (1914), with the percentage of carbonate and bicarbonate recovered and the green weight of wheat obtained. The solid black line on the left at each series number indicates the percentage of sodium carbonate added to the soil; the line at the right shows the percentage recovered at the end of the experiment. The solid portion of the line shows the carbonate and the hatched portion the bicarbonate. The curve at the right of the figure shows the relative growth of the plants in each series of pots.

A comparison of the data on loam and Monterey sand (Table III) shows that the decrease in the yield of the plants was much more rapid in the sand than in the loam. The apparent loss of carbonates was much greater in the loam than in the sand. The loam soil also showed a steady increase in the amount of recoverable sodium bicarbonate, which was not the case with the sand.

A marked difference is to be noted in the green weight of the plants grown in the loam and in the sand. In the check pots the green yield from the sand series was only 62 per cent of the yield of the plants in the loam, although the average height of the plants in the two series was approximately the same.

The data presented in Table III are shown graphically in figures 3 and 4.

TABLE III.—*Results of experiment 3 (1915), giving the effect of sodium carbonate in loam soil and in Monterey sand on the germination and growth of wheat*

Series No.	Sodium carbonate.		Sodium bicarbonate recovered from soil.[1]	Total carbonate salts recovered.	Number of plants.	Green weight of plants.			Decrease in yield from check pot.
	Added to soil.	Recovered from soil.				Pot 1.	Pot 2.	Total.	
	Per ct.	*Per ct.*	*Per cent.*	*Per cent.*		*Gm.*	*Gm.*	*Gm.*	*Per ct.*
LOAM SOIL.									
1	0	0	0	0	10	0.791	0.700	1.491	0
2	.05	0	.03	.019	10	.725	.782	1.507	0
3	.10	0	.05	.032	10	.535	.708	1.243	17
4	.15	0	.04	.025	10	.588	.629	1.217	19
5	.20	0	.05	.032	10	.666	.520	1.186	21
6	.25	0	.08	.050	9	.497	.420	.917	38.5
7	.30	0	.10	.063	8	.255	.538	.793	47
8	.35	0	.16	.101	5	0	.351	.351	76
9	.40	.008	.18	.122	4	.186	.077	.263	83
10	.50	.013	.21	.145	0	0	0	0	100
11	.60	.023	.22	.162	0	0	0	0	100
MONTEREY SAND									
1	0	0	0	0	10	.486	.445	.931	0
2	.05	.003	.066	.045	10	.176	.176	.352	62
3	.10	.013	.087	.068	6	.069	.030	.099	89
4	.15	.016	.119	.091	5	.027	.024	.051	96
5	.20	.049	.132	.132	0	0	0	0	100
6	.25	.080	.116	.153	0	0	0	0	100
7	.30	.096	.125	.175	0	0	0	0	100
8	.35	.140	.137	.226	0	0	0	0	100
9	.40	.244	.150	.344	0	0	0	0	100

[1] In excess of sodium bicarbonate in soil at beginning of experiment.

THE EFFECT OF SODIUM BICARBONATE ON WHEAT SEEDLINGS

EXPERIMENT 4.—In order to determine the relative toxicity of the carbonate salts when added to a soil in the form of sodium bicarbonate, experiment 4 was undertaken in the summer of 1914. The technique of this experiment was the same as that of the experiments previously described, the series of pots being triplicated. The soil used was of the same type as that in experiment 2. The range of salts added to the soil was greater than in the first two experiments, including series numbered 8, 9, and 10, in which were added 0.80, 1, and 1.25 per cent of sodium bicarbonate. Since there was no germination or growth in these series, they have not been included in Table IV, which gives a summary of the results of the experiment.

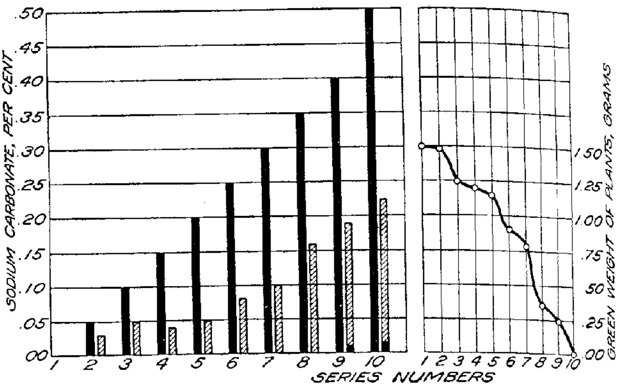

FIG. 3.—Diagram of the percentage of sodium carbonate added to the loam soil in experiment 3 (1915), with the percentage of carbonate and bicarbonate recovered, and green weight of wheat. The solid black line on the left at each series number indicates the percentage of sodium carbonate added to the soil; the line at the right shows the percentage recovered at the end of the experiment. The solid portion of the line shows the carbonate and the hatched portion the bicarbonate. The curve at the right of the figure shows the relative growth of the plants in each series of pots.

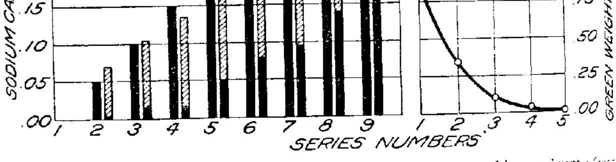

FIG. 4.—Diagram of the percentage of sodium carbonate added to Monterey sand in experiment 3 (1915), with the percentage of carbonate and bicarbonate recovered and the total green weight of wheat obtained. The solid black line on the left at each series number indicates the percentage of sodium carbonate added to the soil; the line at the right shows the percentage recovered at the end of the experiment. The solid portion of the line shows the carbonate and the hatched portion the bicarbonate. The curve at the right of the figure shows the relative growth of the plants in each series of pots.

TABLE IV.—*Results of experiment 4 (1914), giving the effect of sodium bicarbonate on the germination and growth of wheat*

Series No.	Sodium bicarbonate.		Sodium carborate recovered from soil.	Total carbonate salts recovered.	Number of plants.	Green weight of plants.				Decrease in yield from check pots.
	Added to soil.	Recovered from soil.				Pot 1.	Pot 2.	Pot 3.	Total.	
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Per ct.*
1	0	0	0	0	15	0.996	0.917	1.032	2.945	0
2	.05	0	0	0	15	1.051	.790	.905	2.746	6.8
3	.10	.012	0	.008	15	.856	.841	.929	2.626	10.8
4	.20	.029	0	.018	15	.981	.873	.819	2.673	9.2
5	.30	.071	0	.045	15	.362	.460	.371	1.193	59.5
6	.40	.088	.021	.076	5	.065	.114	.070	.249	91.5
7	.60	.071	.074	.119	0	0	0	0	0	100

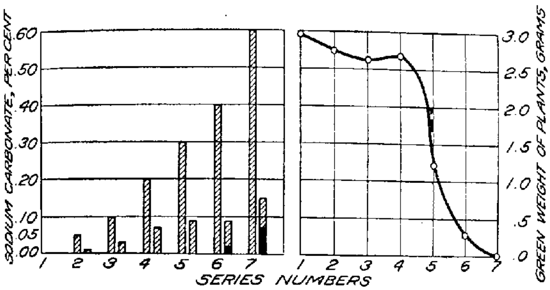

FIG. 5.—Diagram of the percentage of sodium bicarbonate added to the soil in experiment 4 (1914), with carbonate and bicarbonate recovered, together with the total green weight of wheat obtained. The solid black line on the left at each series number indicates the percentage of sodium carbonate added to the soil; the line at the right shows the percentage recovered at the end of the experiment. The solid portion of the line shows the carbonate and the hatched portion the bicarbonate. The curve at the right of the figure shows the relative growth of the plants in each series of pots.

The first noticeable feature of this experiment is the discrepancy between the amount of bicarbonate added to the soil and the amount finally recovered. There was also evidence of a conversion of the bicarbonate to the carbonate form in the last two series. In this case, as in experiment 2, there was a decrease of growth in series 2, even though no carbonate salt was recoverable at the end of the experiment.

The data presented in Table IV is shown graphically in figure 5.

COMPARATIVE TOXICITY OF SODIUM CARBONATE AND SODIUM BICARBONATE

A comparison of experiments 2 and 4, in which the carbonate and bicarbonate salts were used, shows that these two salts have approxi-

mately the same toxic effect when the total of the carbonate salts recoverable is considered rather than the percentage of salts added to the soil. In other words, the toxicity of these salts in the soil is directly associable with the quantity of the basic radical in the salt recoverable. The close relationship between the results of these two experiments is shown in figure 6, in which the curves of decrease in growth are constructed on the same scale.

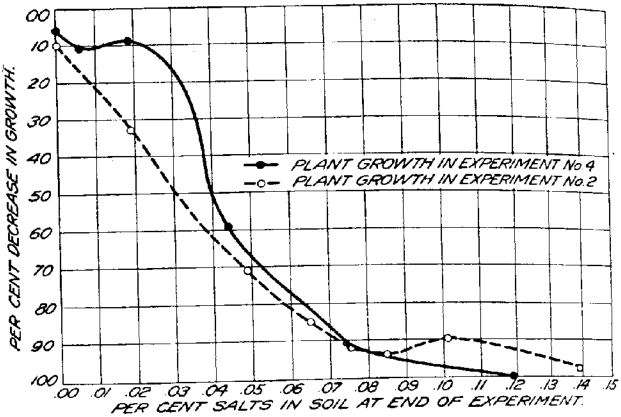

FIG. 6.—Diagram of the decrease in growth of wheat seedlings in experiments 2 and 4 as affected by the total carbonate salts recoverable from the soil. The solid black line on the left at each series number indicates the percentage of sodium carbonate added to the soil; the line at the right shows the percentage recovered at the end of the experiment. The solid portion of the line shows the carbonate and the hatched portion the bicarbonate. The curve at the right of the figure shows the relative growth of the plants in each series of pots.

EFFECT OF SODIUM CHLORID ON WHEAT SEEDLINGS

EXPERIMENT 5.—At the same time the carbonate and bicarbonate experiments in 1914 were in progress (experiments 2 and 4) a similar experiment with sodium chlorid was carried on with the same soil. The general plan and manipulation was the same as has been described above. The wheat was allowed to grow for 16 days. The original soil contained only 0.006 per cent of sodium chlorid.

A summary of the results obtained in this experiment is given in Table V. It is possible to compare these results directly with those obtained in the carbonate, bicarbonate, and sulphate experiments in 1914, as the soil used was the same in all cases.

TABLE V.—*Results of experiment 5 (October, 1914), giving the effect of sodium chlorid in soil on the germination of wheat seedlings*

Series No.	Sodium chlorid.		Number of plants.	Green weight of plants.				Decrease in yield from check pots.
	Added to soil.	Recovered from soil.		Pot 1.	Pot 2.	Pot 3.	Total.	
	Per ct.	*Per ct.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Per ct.*
1	....	....	15	0.943	0.852	0.980	2.776	....
2	0.05	0.04	15	.824	.818	.821	2.464	11.0
3	.10	.09	13	.724	.646	.642	2.013	27.5
4	.20	.16	13	.420	.430	.562	1.412	49.0
5	.30	.26	5	.115	.093	.178	.388	86.0
6	.40	.32	5	0	.029	.015	.044	98.4
7	.60	.52	0	0	0	0	0	100.0

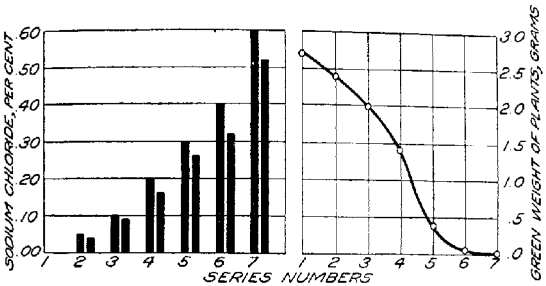

FIG. 7.—Diagram of the quantity of sodium chlorid added to the soil, with the quantity of chlorid recovered, and the total green weight of wheat obtained. Experiment 5. The left-hand column above the series number represents the percentage of sodium chlorid added and the right-hand column the percentage recovered from the soil. The curve at the right represents the weight (in grams) of the green wheat.

It is clear from the results given in Table V that the absorptive power of the soil for sodium chlorid is much less than for sodium carbonate. An average of 85 per cent of the chlorid was recovered, and a 50 per cent decrease in yield took place in the soil from which 0.16 per cent of the salt was recovered.

The results of Table V are shown graphically in figure 7.

EFFECT OF SODIUM SULPHATE ON WHEAT SEEDLINGS

EXPERIMENT 6.—The experiment with sodium sulphate was conducted in the same manner and at the same time and with the same lot of soil as experiments 2, 4, and 5. The moisture content of the soil was kept at 16 per cent and the wheat was allowed to grow for 16 days. The results are summarized in Table VI.

TABLE VI.—*Results of experiment 6 (1914), giving the effect of sodium sulphate on wheat seedlings*

Series No.	Sodium sulphate.		Number of plants.	Green weight of plants.				
	Added to soil.	Recovered from soil.		Pot 1.	Pot 2.	Pot 3.	Total.	Decrease in yield from check pot.
	Per cent.	*Per cent.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Per cent.*
1	0	0	15	0.941	0.957	0.916	2.815	.....
2	.05	0	15	.810	.968	.795	2.574	8.5
3	.10	.07	15	.975	.987	.815	2.778	0.5
4	.20	.16	14	.728	.573	.936	2.238	20.5
5	.30	.19	14	.610	.597	.713	1.920	31.5
6	.40	.25	15	.685	.693	.592	1.971	30
7	.60	.35	15	.513	.360	.430	1.303	53.5
8	.80	.37	11	.091	.277	.346	.715	75
9	1.00	.45	10	.028	.163	.076	.268	90.5
10	1.25	.56	0	0	0	0	0	100

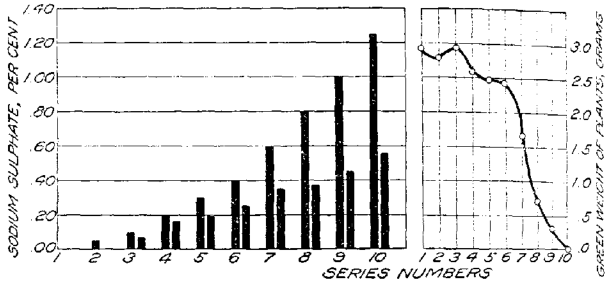

FIG. 8.—Diagram of the quantity of sodium sulphate added to the soil in experiment 6, the quantity recovered, and the total green weight of wheat obtained. The left-hand column above the series number represents the quantity of sodium sulphate added and the right-hand column the quantity recovered. The curve at the right represents the weight (in grams) of green plants from each series.

In the preceding experiments it was found that this same sandy loam soil absorbed an average of 77 per cent of the sodium carbonate, 85 per cent of the sodium bicarbonate, and 15 per cent of the sodium chlorid added. In this experiment with sodium sulphate it was found that the amount absorbed was 53 per cent of that added.

The toxicity of this salt was also considerably less than that of any of the other salts mentioned. In the case where 0.16 per cent of the sulphate was recovered, the yield was reduced only 20 per cent, while an equal amount of sodium chlorid reduced the yield 49 per cent. The percentage of germination was not affected in the case where 0.35 per cent of sodium sulphate was recovered, but it was noticed that the time required for germination was materially lengthened as the percentage of the sulphate increased.

Figure 8 shows graphically the results given in Table VI.

COMPARATIVE TOXICITY OF THE SODIUM SALTS

In view of the fact that the carbonate and bicarbonate of sodium appear to be interchangeable in the soil, the comparisons of toxicity may be made between the total carbonate salts as previously defined and sodium chlorid and sodium sulphate. Assuming that a reduction of growth of approximately 50 per cent of the check is a critical point of toxicity at which comparisons can be made, it is found that this point is reached with 0.04 per cent of total carbonate salts, with 0.16 per cent of sodium chlorid, and 0.35 per cent of sodium sulphate, using the quantities of salt recoverable from the soil—that is, the carbonate salts are four times as toxic as the chlorids and eight times as toxic as the sulphates.

If the limit of tolerance for the wheat seedling is taken as the point of concentration when both growth and germination are prevented, this is found to be with the carbonate 0.13 per cent, with sodium chlorid 0.52 per cent, and with sodium sulphate 0.56 per cent. It is not clear why there is so little difference in these experiments between the limit of tolerance for sodium chlorid and sodium sulphate.

SUMMARY

(1) In reclaiming a tract of salt land in Nevada laboratory experiments were carried on to determine the limits of tolerance of certain crop plants to the common salts of sodium.

(2) These laboratory experiments brought out the fact that only a part of the salt added to the soil in pot cultures could later be recovered from it by water digestion.

(3) This apparent loss of salt, which was probably due to absorption by the soil, was greater in the case of sodium carbonate and sodium sulphate than with sodium chlorid.

(4) Where sodium carbonate was added to a soil the absorption was greater in fine soil, rich in organic matter, than in sand.

(5) The limit of tolerance of crop plants to the salt in the soil is determined by the quantity of salt that can be recovered from the soil rather than by the quantity added to the soil.

(6) The carbonates and bicarbonates of sodium are mutually interchangeable in the soil and the toxicity of the soil solution appears to depend upon the quantity of the basic radical held in the soil regardless of the form of the acid radical.

(7) In the case of the soil from the field under consideration, the proportion of recoverable salt which would reduce by one-half the growth of wheat seedlings was for the carbonates 0.04 per cent of the dry weight of the soil, for the chlorids 0.16 per cent, and for the sulphates 0.35 per cent.

(8) The proportion of recoverable salt which prevented germination of wheat was for the carbonates 0.13 per cent, for the chlorids 0.52 per cent, and for the sulphates 0.56 per cent.

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